Resource Recovery

SOLID WASTE FOR INDUSTRIAL FUEL

PREPARED BY

ENVIROCON LTD.

FOR

THE MINISTRY OF THE ENVIRONMENT

AND

THE MINISTRY OF ENERGY

Ontario

Ministry
of the
Environment

Solid waste for industrial fuel /

ONTARIO MINISTRY OF ENVIRONMENT
RESOURCE RECOVERY BRANCH

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SUMMARY

There are environmental and social advantages in using solid waste as industrial fuel in preference to sanitary land fill and incineration disposal. In general terms, technical and economic feasibility is promising; however, each potential situation must be examined on a site-specific basis. Criteria for industrial plants which favour use of solid waste as fuel include:

- a minimum heat requirement of about 100,000 BTU per hour

- high cost and short supply of conventional fuels

- limited seasonal variation for fuel use

- plant locations in heavy industrial areas near major population centres

- employment of relatively complex production technology

Industries which generally meet the above criteria have capacity to utilize perhaps 20 million tons of solid waste per annum. In comparison, current waste generation is about 7 million tons per annum for all of Ontario and about 2 million tons for metropolitan Toronto. Replacement of conventional fuel, equivalent to 7,500 barrels of oil per day, is a reasonable goal for Ontario. Clearly, use of solid waste as industrial fuel could be a major feature of provincial waste management strategy.

While technology for combustion of solid waste is in a comparatively early stage of development, feasible systems for industrial application are available. Assessment of the state-of-the-art indicates that refuse derived fuel (RDF), incineration with heat recovery and pyrolysis/gasification can be employed. The optimal technical and economic approach is dependent upon the characteristics of each case and varies significantly from situation to situation.

A focus of this study was on the emerging technology of pyrolysis/gasification. A pragmatic state-of-the-art assessment indicates that five systems are commercial or are likely to become commercial during 1977. The features of these five systems are significantly different and selection of the optimal system is dependent on the characteristics of the specific case.

It is recommended that promising situations for use of solid waste as industrial fuel be identified and technical and economic feasibility be examined for one or more cases. Further, it is recommended that market and feasibility studies be carried out to assess the potential for use of RDF as a prime or supplementary fuel for industrial coal-fired boilers.

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APPENDICES

1.0 INTRODUCTION

During the last several years, prices of prime petroleum fuels, natural gas and fuel oil, have increased rapidly and limitations of domestic petroleum reserves have become apparent to a wide sector of the public and industry. This trend provides impetus to industry to search for lower cost, more available fuels, such as coal and solid waste. Utilization of solid waste as fuel not only conserves scarce energy resources but also could contribute to a solution for a difficult environmental problem - disposal of solid waste generated by residential communities, commercial establishments and industry.

To date, planning and implementation of projects for recovering material and fuel values from solid wastes has centered on public agencies and has emphasized large central plants serving populations of greater than 400,000, processing perhaps 1000 tons of solid waste per day. There are, however, potential advantages which might be realized if smaller scale facilities associated with industrial plants were constructed. Advantages of this approach include:

- The location of industrial plants is often appropriate for a solid waste disposal/utilization facility with respect to transport, land use and environmental considerations.

- Typical industrial boilers or direct-fired process units have capacities in the range of 100 to 200 million

BTU per hour. To meet a heat requirement of this size, 350 to 700 tons of solid waste per day, generated by a population of 200,000 to 400,000, is required. A volume of this magnitude is often not considered viable for a regional incineration facility.

- Corrosion problems arising from combustion of PVC plastic materials contained in solid waste can be reduced if steam generation temperatures are maintained below 425° C (800° F). Industrial boilers generally operate below this critical temperature, while to maximize thermal efficiency, utilities almost always generate steam at higher temperatures.

- Industrial fuel requirements for process energy are relatively constant on an annual basis. It is more difficult to integrate solid waste fired facilities with central heating and cooling systems due to substantial annual variation.

- Industrial process-plant staff have the technical skills required for operation and maintenance of complex solid waste conditioning, material recovery and combustion systems.

Use of solid waste as industrial fuel is constrained by technical limitations of energy conversion systems and high capital costs. During recent years, substantial research and development efforts in North America, Europe and Japan

have been focused on these problems. It is considered that systems capable of reliable and controlled operation using heterogeneous solid waste with varying heat values and physical characteristics, operating in accordance with governing environmental standards, are now developed to the point where they can be considered for commercial industrial applications.

This study comprises an overview of the potential for utilizing solid waste as an industrial fuel, considering current technical and economic factors. Analysis focuses on new technology, in particular pyrolysis/gasification systems capable of converting mixed waste materials to fuel gas and non-combustible residue. Other more conventional approaches, incineration with heat recovery and combustion of refuse derived fuel (RDF) in existing boilers, are also assessed.

A definitive analysis of feasibility is only possible for a site-specific case. The objective of this overview study was to assess the value of undertaking a site-specific study or studies and to provide basic analysis of technical and economic factors governing selection and evaluation of industrial applications for using solid waste as fuel.

2.0 POTENTIAL FOR UTILIZATION OF SOLID WASTE AS INDUSTRIAL FUEL

2.1 General

Assessment of potential for use of solid waste to replace conventional industrial fuels is facilitated by examining statistics on fuel requirements of Ontario manufacturing industries. Data compiled by the Ontario Statistical Centre shows 1972 consumption of fuel oil, natural gas and coal by some 12,500 establishments employing almost 800,000 people, as being roughly equivalent to the energy available from burning 47 million tons of solid waste. This compares with the estimated municipal solid waste generated in the province of approximately 7 million tons (1974), of which almost 2 million tons originates in metropolitan Toronto.

If 2 million tons of solid waste were used each annum, the reduction in consumption of our scarce conventional fuels would be equivalent to approximately 7,500 barrels of oil per day.

Total industrial fuel consumption and consumption of selected industries for the year 1972 are summarized in Table 1.

Abbreviations used in this report are listed in Appendix 1.

TABLE 1

FUEL CONSUMPTION OF SELECTED ONTARIO INDUSTRIES, 1972

SIC Class	Category	Fuel Oil (Million I Gal)	Natural Gas (Million MCF)	Coal (Thousand Tons)
-	All Industries	665	228	1,207
Selected Industries				
162	Rubber Products	20.4	2.3	1.3
291	Iron and Steel*	85.9	30.9	-
323	Motor Vehicle Mfrs.	16.6	4.5	105.8
325	Vehicle Parts Mfrs.	12.6	6.7	34.8
351	Clay Products	1.8	4.5	-
352	Cement Mfrs.	41.6	8.9	138.2
356	Glass Mfrs.	1.3	10.3	.2
358	Lime Mfrs.	11.3	3.6	28.6
378	Industrial Chemicals*	105.6	34.8	14.4
Total Selected Industries		297	107	323**

Source: Reference 1 (see references as listed in Appendix 2).

* Coal or natural gas used as a process raw material is not included in the above values.

** Two major coal users not included among the selected industries, because of typical non-urban plant locations are:

SIC 271, Pulp and Paper - 295,000 tons/annum

SIC 295, Smelting and Refining - 545,000 tons/annum

The potential for waste utilization varies greatly from industry to industry. In qualitative terms, criteria which contribute to the likelihood of using solid waste for fuel include:

- Relatively high fuel volume requirement per establishment or plant - a minimum of 100,000 BTU per hour, which can be obtained from 350 tons per day or about 115,000 tons per annum of solid waste. 2

  see pg. 1

- High cost and short supply of conventional fuels - natural gas, oil and coal.

- Use of fuel for process energy, rather than for space heating, thus limiting seasonal variance.

- Plant locations in heavy industrial areas near major population centers.

- Employment of relatively complex production technology, thus providing a source of technical capability required for operation and maintenance of systems to convert solid waste to useful energy forms.

2.2 Selected Industries

Several industry classifications may be identified as having high potential for using solid waste as fuel. The industries segregated in the accompanying tables have been arbitrarily selected, based on the above criteria. The potential for

replacement of oil, gas and coal by these industries is indicated by Tables 2, 3 and 4.

TABLE 2
POTENTIAL FOR SOLID WASTE UTILIZATION BY SELECTED ONTARIO INDUSTRIES

SIC Class	Category	Oil and Natural Gas Replacement	Coal Replacement	Total
		Thousand Tons/Annum		
-	All Industries	42,500	4,500	47,000
Selected Industries				
162	Rubber Products	720	5	725
291	Iron and Steel	5,700	--	5,700
323	Motor Vehicle Mfrs.	910	400	1,310
325	Vehicle Parts Mfrs.	1,100	130	1,230
351	Clay Products	600	--	600
352	Cement Mfrs.	2,000	500	2,500
356	Glass Mfrs.	1,300	--	1,300
358	Lime Mfrs.	690	110	800
378	Industrial Chemicals	6,600	55	6,655
Total Selected Industries		19,600	1,200	20,800

Source: Reference 1

Based on:
1. Fuel Oil: 170,000 BTU/1 Gal
2. Natural Gas: 1,000 BTU/cu.ft.
3. Coal: 15,000 BTU/lb
4. Solid Waste: 4,000 BTU/lb

TABLE 3

POTENTIAL FOR WASTE UTILIZATION

RELATED TO ESTABLISHMENTS AND EMPLOYEES

SIC Class	Categories	No. of Estab.	1000 Emps.	Annual Waste Disposal Potential 1000 Tons/Estab.
-	All Industries	12,600	788	3.8
Selected Industries				
162	Rubber Products	57	15.4	12.7
291	Iron and Steel	17	36.8	335
232	Motor Vehicle Mfrs.	9	34.6	145
325	Vehicle Parts Mfrs.	165	44.6	7.5
351	Clay Products	62	2.6	9.6
352	Cement Mfrs.	6	1.2	417
356	Glass Mfrs.	50	7.1	26
358	Lime Mfrs.	6	.4	133
378	Industrial Chemicals	62	10.9	107
Total Selected Industries		434	154	48

Source: Reference 1

TABLE 4

FUEL CONSUMPTION BY APPLICATION FOR

SELECTED ONTARIO INDUSTRIES

SIC Class	Categories	% Consumption Process	Heating*	Power	Total Fuel Use (10^{12} BTU/ annum)
-	All Industries	70.9	23.7	5.4	
Selected Industries					
162	Rubber Products	84.9	12.9	2.2	5.82
291	Iron and Steel	76.5	13.8	9.7	45.56
323	Motor Vehicle Mfrs.	47.4	52.6	---	10.11
325	Vehicle Parts Mfrs.	23.3	76.7	---	9.87
351	Clay Products	89.9	10.1	---	4.78
352	Cement Mfrs.	94.6	5.4	---	19.59
356	Glass Mfrs.	94.8	5.2	---	10.50
358	Lime Mfrs.	96.8	3.2	---	6.29
378	Industrial Chemicals	71.8	6.4	21.8	55.04
Total Selected Industries		74.7	15.4	9.9	168.

* Includes space heating and heating of make-up air.

Source: Ontario Ministry of Energy

Generally these industries use fuel predominantly for process energy rather than for space heating, are located in major urban areas, and each establishment is of a relatively large size. The forest industry, one of the largest energy consumers in the province, has not been included among the selected industries because the large majority of plants are located in areas with low population density, and wood waste, hog fuel, is a more attractive replacement for conventional fuels than would be solid waste.

On an aggregate basis, the potential to utilize perhaps 20 million tons of solid waste per annum easily exceeds the availability of waste material. Thus, consideration of solid waste as an industrial fuel is a relevant topic and clearly warrants attention.

Technical and economic feasibility cannot, however, be established on a general basis. The characteristics of each potential application - average fuel requirement, seasonal variance, location, technical requirements and cost of competitive fuels - are unique and vary substantially.

2.3 Technical Constraints

A major portion of the fuel used by industry is for generation of steam. For this application, conventional tumbling grate or semi-suspension incinerators with heat recovery,

refuse derived fuel (RDF) in coal-stoker type boilers, and more sophisticated pyrolysis/gasification systems may be employed. The selection of the most appropriate system is a question of technology, scale and economics.

Other applications, where the process is direct fired, such as cement and lime kilns, pose a more difficult problem. For these cases, fuel characteristics, moisture and ash content, stoichoimetric flame temperature, excess air requirement and combustion gas volume and composition, may have a significant and possibly detrimental affect on production volume and quality. Direct firing applications may require extensive preparation of RDF - drying and removal of non-combustibles. Alternatively, pyrolysis/gasification systems which produce a clean, dry fuel gas with a relatively high BTU value may be suitable.

The requirement to meet air emission environmental standards also poses technical limitations. Because solid waste is a highly variable, high moisture content, high ash material, maintenance of stack emission standards is substantially more difficult and costly than with better fuels.

2.4 Constraints Limiting Solid Waste Fuel Application

Several limitations impinge on potential to utilize solid waste as an industrial fuel:

- High capital and operating costs.

- Technical problems.

- Constraints, legal and political, on possible contractual conditions between municipal agencies and private industry.

The first two limitations are, of course, related. Considerable effort is currently being devoted to development of improved technology for utilization of solid waste as fuel. This research and development should contribute to cost reductions in real terms, as well as enhancing technological feasibility. Of possibly even greater significance in enabling economic feasibility is the steadily increasing cost of conventional fuels. The fuel value of municipal solid waste (MSW) is related to costs of conventional fuels in Table 5 .

TABLE 5

VALUE OF SOLID WASTE AT SELECTED COSTS FOR ALTERNATIVE FUELS

	Unit	1972	1976	1980
Fuel Oil				
Typical Cost	\$/Barrel	4.20	12.00	18.00
Unit Cost	\$/$\bar{M}$BTU	.70	2.00	3.00
MSW Value	\$/Ton	5.60	16.00	24.00
Natural Gas				
Unit Cost	\$/$\bar{M}$BTU	.57	1.40	3.50
MSW Value	\$/Ton	4.56	11.20	28.00
Coal				
Typical Cost	\$/Ton	18.17	50.00	65.00
Unit Cost	\$/$\bar{M}$BTU	.62	1.66	2.15
MSW Value	\$/Ton	5.00	13.30	17.30

Based on:
1. Same unit fuel values as Table 2.
2. Costs for 1972 from Reference 1.
3. Envirocon estimate for 1976 and 1980.
4. All costs expressed in current dollars.

It is very likely that the present trend for increasing fuel cost, particularly for premium fuels such as natural gas, to increase in real terms (deflated dollar costs) will continue. Thus, the economic feasibility of using solid waste for fuel will be more favourable in the future.

Legal and political constraints which may impede or limit contractual agreements required for industry to use publicly collected solid waste could be important. Nevertheless, it is considered that if social benefits are significant, such limitation can be overcome and a specific assessment is not necessary or appropriate for this overview analysis.

3.0 PYROLYSIS/GASIFICATION

3.1 State-of-the-Art

As indicated in the Introduction a focus of this study has been on pyrolysis/gasification (P/G) systems which convert solid waste into a fuel gas of varying quality and a solid residue. P/G systems have potential advantages over alternative approaches for conversion of solid waste to useful energy. The principal advantages are:

Flexibility. Adequately treated fuel gas can be used for a variety of applications, including steam generation, conversion of existing gas/oil boilers and direct firing of process heaters, dryers and cement and lime kilns.

Conformance with Environmental Standards. Stack emissions from conventional combustion units operating on solid waste are difficult to treat and control to conform with emission standards. P/G fuel gas can be conditioned prior to combustion and the resultant products are comparable to flue gases from natural gas combustion. The ash produced by P/G systems is only a small volume of the incoming refuse and land-fill disposal presents far fewer problems to avoid environmental damage.

Scale. P/G systems, which can be charged with raw or only partially treated waste, could be economically feasible at relatively low capacity ratings - 300 to 400 tons per day. (Some P/G systems embody substantial

economies of scale and likely will only be feasible at operating rates exceeding 1,000 tons per day.)

The budget for this study did not provide for a systematic search of the pertinent literature. Nevertheless, a wide range of publications and corporate data was reviewed and the analysis is a practical and complete assessment of the state-of-the-art.

It is considered that five P/G systems are currently available on commercial contractual terms or will be so available in the near future. These are identified below and are more fully described and compared in succeeding sections.

Andco-Torrax. High temperature, slagging, vertical-shaft unit; produces inert frit and high-temperature, low-BTU gas best suited for close coupled steam generation; requires very limited solid waste (front end) preparation; three commercial units under construction.

Monsanto Enviro-Chem. High temperature, rotary kiln system; produces char/ash sludge and high-temperature, low-BTU gas best suited for close coupled steam generation; requires moderate front end preparation; 1,000 ton per day demonstration plant is in operation.

Moore Powergas. Low temperature vertical reactor unit; produces dry inert ash and low-temperature, low-BTU gas suited for direct firing as well as for close coupled steam generation; requires moderate front end preparation;

200 ton per day demonstration plant operated on woodwaste started up in April 1976.

Occidental Research. Entrained flow reactor; produces synthetic oil and high ash char; requires extensive front end preparation; 200 ton per day demonstration plant scheduled for September 1976 start-up.

Union Carbide. High temperature, slagging, vertical shaft unit; blown with oxygen; produces inert frit and low-temperature, medium-BTU gas well suited for direct firing as well as for close coupled steam generation; requires moderate front end preparation; 200 to 300 ton per day demonstration plant in operation since early 1975.

Several other firms have developed or are developing P/G systems. It is considered, however, that these systems are not currently available for commercial application and that timing for commercial application is less certain than for the five selected systems. These systems include:

CIL Environmental Improvement Business Area, Toronto. A 25 ton per day pilot plant is scheduled to be put into operation in mid-April 1976. Utilizes fluidized bed reactor.

Alberta Industrial Developments Ltd., Edmonton. A 50 ton per day pilot plant, previously operated at Edmonton, is being relocated to Wisconsin. Company reports that several other plants are to be constructed in Oregon and California to operate on hog fuel. Design is based on

fluidized bed technology developed by British Columbia Research.

Tech-Air Corporation, Chamblee, Georgia. (American Can subsidiary). Operate a very small pilot plant in Georgia producing char, oil and gas by pyrolysis of woodwaste. Not yet prepared to sell on commercial basis, except possibly very small units.

Coors Brewery, Denver, Colorado. Operated a one ton per hour fluidized bed unit for several years. Unit is now shut down and firm has no plans to develop or market.

Battalle Pacific Northwest Laboratories, Richland, Washington. Operated a 2.5 ton per day pilot plant during 1972 under a program funded by the City of Kennewick, Washington, EPA and Battelle. Tests provided good indication of success, but no subsequent development work has been undertaken or is planned.* Concept is very similar to that employed by Moore Powergas.

Several other firms have or are developing P/G technology, but available information is limited and attempts to contact these firms were not successful. It is believed that several of the firms, listed below, are no longer active.

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* Data and observations are well summarized in Reference 4.

Syngas Recycling Corp., Toronto, Ontario
American Thermogen Inc., College Point, N.Y.
Hercules Incorporated, Wilmington, Delaware
Pyrotechnic Industries Ltd., Cochrane, Alberta
Pyrolysis Systems, Riverside, California

The technical characteristics of the five P/G systems considered to be commercial or near-commercial are discussed more fully in the following sections.

3.2 Andco-Torrax

Development of the P/G system was initiated in 1969 jointly by Andco Inc. and the Carborundum Company. A pilot plant with a capacity of 75 tons per day was put into operation at Orchard Park, N.Y. in mid-1971. Development has been funded privately and by the U.S. Environmental Protection Agency. In Canada, the system is marketed by Andco-Torrax Limited of Burlington, Ontario.

In addition to the pilot plant, Andco-Torrax has three systems under construction in Europe.

	Capacity (tons/day)	Scheduled Start-Up
Luxembourg	200	mid 1976
Grasse, France	170	late 1976
Frankfurt, Germany	200	late 1976

The key component of the Andco-Torrax system is a vertical shaft gasifier similar in structure to a cupola furnace. Drying, pyrolysis, gasification and combustion reactions are carried out concurrently in this unit.

Untreated solid waste is charged directly into the top of the reactor, which is operated at a slight negative pressure to obviate the need of a feed air lock. A partial seal is provided by the descending plug of solid waste. Preheated 1100°C (2000°F) air is supplied to the base of the reactor to maintain the combustion zone at a temperature of about 1650°C (3000°F). At this temperature non-combustible materials are transformed to molten slag which is continuously tapped and water quenched to produce a black, glassy frit. The gases from partial combustion of the solid wastes along with distilled volatiles and hydrogen and carbon monoxide produced by gasification of fixed carbon are drawn off at a latern section at the mid-section of the reactor.

The fuel gas mixture, at a temperature of about 450°C (800°F), containing significant quantities of water vapour, tar and particulates, has a heating value of about 100 BTU per cu ft. In the standard Andco-Torrax system this hot fuel gas is mixed with the required combustion air and burned in a secondary combustion chamber. Temperature, turbulence and residence time are sufficient to burn the tars and combustible particulates. A large portion of the inert material is also fused and mechanically separated from the hot gas stream in this secondary chamber.

The major portion (85 percent) of the combustion products is directed to a waste heat boiler to generate three to four pounds of steam per pound of solid waste. A side stream is used to heat the combustion air required for the gasification reaction. Following the waste heat boiler, the combustion products are directed to an electrostatic precipitator to remove remaining particulate.

A complete description of the equipment and process is contained in Reference 2. The Andco-Torrax and other principal P/G systems are compared in Appendix 3.

While the Andco-Torrax unit has potential to produce low-BTU fuel gas for direct firing applications, development to date has emphasized integration with a specialized close-coupled steam generator. To permit firing the fuel gas in conventional gas burners, tars, particulate and water vapour must be removed. This requires cooling the hot off-gases and substantially reduces system thermal efficiency. It is possible that modification of the gasifier configuration and operation could produce a cooler, cleaner gas and Andco-Torrax may in the future elect to develop a modification of the existing system better suited for production of fuel gas.

Andco-Torrax are prepared to enter into a typical commercial contract for system supply. Front end treatment requirements are limited and reactor size will be a maximum of about 400 tons per day. Economies of scale are somewhat limited and a capacity of 200 to 400 tons per day could be economically attractive and well suited for industrial application.

3.3 Monsanto Enviro-Chem

The "Landgard" system of Monsanto was developed over a two year period using a 35 ton per day plant located at St. Louis. More recently, a 30 ton per day plant was constructed by a licensee, Kawasaki Heavy Industries at Kobe, Japan. In 1973, Monsanto commenced construction of a 1000 ton per day demonstration plant funded by the City of Baltimore and the U.S. Environmental Protection Agency.

The Baltimore demonstration plant, completely described in Reference 3, features a refractory-lined, horizontal, rotary kiln gasifier. Partially shredded waste, minus four inch particle size, is conveyed from storage to the feed end of the 19 foot diameter by 100 foot kiln. Combustion air along with 7.1 gallons of No 2 oil per ton of waste is directed to the firing end of the kiln to pyrolyze and partially combust and gasify the waste. Gasification is not complete and the residue is about 25 percent carbon char by weight. Total residue is about 32 percent by weight of the waste feed. The off-gases are combusted in an afterburner and directed to a waste heat boiler where approximately 2.4 lbs of steam is generated per lb of waste.

A scrubber following the boiler removes particulate. Performance, however, is not adequate to conform with required emission standards and an electrostatic precipitator is to be installed at the Baltimore plant.

Inability to control off-gas temperatures is the key to relatively major problems which have been encountered. Gas temperature is running at 800°C (1500°F) rather than the 650°C (1200°F) design value. Increased particulate loadings and ash handling problems result from the higher gas temperature.

The high temperature of the off-gas makes conditioning of fuel gas for combustion in conventional burners thermally inefficient. Furthermore, economies of scale inherent with a kiln reactor may limit potential of the Landgard system for industrial applications. A capacity of 1000 tons per day may be a lower limit for this system.

Until such time as mechanical and emission difficulties are resolved, tentatively by year end 1976, detailed operating data on the Baltimore demonstration plant will not be publicly available and the system will not be offered for sale by Monsanto.

3.4 Moore Powergas

The Powergas P/G system was developed principally for wood wastes (hog fuel) rather than for municipal solid wastes. A pilot unit is located at Moore's plant in Vancouver and a 240 ton per day demonstration plant was put into operation at a sawmill in the interior of British Columbia in early April 1976. To date, limited public information is available on the detailed characteristics of the Powergas system.

The principal features of operation are similar to a pilot plant operated by Battelle Pacific Northwest Laboratories during 1972, as reported in Reference 4. Hog fuel or solid waste is charged to a vertical refractory-lined reactor through a rotary air-lock. Dry ash is removed at the bottom through an ash removal, air-lock device and relatively cool pyrolysis and combustion gases are drawn off near the top of the reactor.

Combustion air and gasification steam supply is controlled to limit temperatures to about 1000°C (1800°F) to prevent slagging of the ash. Equilibrium is established within the reactor such that the off-gas is withdrawn from the unit at about 100°C (200°F). Addition of steam with the combustion air promotes the water-gas reaction and almost complete gasification of fixed carbon is reported to be possible.

The heat value of the gas produced from solid waste is in the range of 150 BTU per cu ft. The relatively cool temperature of the gas makes removal of water vapour as well as particulate and tars by means of a cooler/scrubber technically and economically feasible. Thus, the Powergas configuration is suitable for producing low-BTU gas for firing in conventional burners as well as for close coupled steam generation.

Powergas contemplate standardizing the size of the reactor at about 10 ft diameter by 30 ft high and anticipate a reactor capacity of approximately 120 tons per day on

hog fuel or 100 tons per day on solid wastes. The Battelle studies indicate this to be a conservative estimate. It is also anticipated that limited conditioning of the raw waste will be required before charging to the reactor. These features make the Powergas system well suited for industrial applications.

Moore are prepared to sell the system on commercial or near-commercial terms. Clearly, however, until the demonstration system currently being operated on hog fuel is proven and until other systems are operated on solid waste, there would be a technological risk associated with such a contract.

3.5 Occidential Research (previously Garrett Research and Development)

The Occidental Research process differs substantially from the other P/G systems with respect to both the reactor configuration and the fuel product. Finely shredded waste is pyrolyzed and gasified in a concurrent flow, entrained bed, reactor to produce pyrolytic oil. Low-BTU fuel gas and char is also produced which is recycled for process heat. There is a surplus of high ash char which must be sent to land-fill.

Approximately 0.9 barrels of pyrolytic oil with a heat value of about 76 percent of the heat value of Bunker C oil are produced per ton of solid waste. This oil can be stored and utilized in conventional oil fired

units although certain special operating procedures must be employed.

The entrained flow reactor requires that solid waste material be very finely sized - minus 14 mesh. To accomplish this, Occidental has developed a complex feed preparation subsystem utilizing two-stage shredding and providing for recovery of ferrous and non-ferrous metals and glass.

A 200 ton per day demonstration plant is currently under construction in San Diego. This plant, scheduled for start-up in late 1976, is described in detail in Reference 5. Occidental anticipates being in a position to market pyrolytic oil plants by mid-1977.

The complex front end and gasification reaction with associated economies of scale tend to make this system most suitable for large operations, a minimum of 1000 tons per day. Furthermore, the flexibility provided by production of an oil fuel which can be stored and transported reduce the requirement to closely integrate solid waste processing with the energy user. The Occidental pyrolysis system is considered to have limited potential for direct industrial application.

3.6 Union Carbide

The "Purox" P/G system developed by Union Carbide features a vertical shaft reactor operating in a slagging mode at

1650°C (3000°F). Heat for drying, pyrolysis and gasification is supplied by combusting a portion of the waste in the reactor using industrial oxygen.

By using oxygen rather than air for combustion, the reactor heat balance is such that the off-gas is withdrawn at a temperature of about 100°C (200°F). Thus, it is feasible to utilize a scrubber/cooler for conditioning of the fuel gas. Furthermore, by using oxygen rather than air, nitrogen content of the fuel gas is negligible and the heat value of the gas is in the medium-BTU range - 350 BTU per cu ft. The gas is suitable for synthesis of products such as methanol and ammonia as well as for fuel.

Waste must be shredded and it is anticipated that ferrous metals would be removed prior to charging to the reactor via a double gate air-lock. Non-combustibles are continuously removed as slag and water quenched to produce inert frit.

A 200 to 300 ton per day demonstration plant has been operated at South Charleston, West Virginia since 1974. This plant is described in Reference 6. Union Carbide has established a standardized reactor size of about 12 ft diameter by 30 ft high, similar to the South Charleston unit, and project a capacity for a commercial unit of 350 tons per day. To ensure guaranteed operating rates, a standby reactor is envisaged.

While reactor capacity is favourable for relatively small plants, economies of scale associated with oxygen production tend to make the feasibility of plants with capacities of less than 700 tons per day uncertain. In some cases, however, it may be feasible to integrate oxygen production with other operations to overcome size/cost penalties.

Although Union Carbide does not have a unit in commercial operation, it is prepared to enter into contracts, which provide operating and cost guarantees, for supply and operation of the Purox system.

3.7 P/G System Summary

The status of the five principal systems with respect to commercial application is summarized as follows.

Andco-Torrax. System essentially proven for close-coupled steam generation but not well suited for production of low-BTU gas for direct firing applications such as cement or lime kilns. Economic feasibility of relatively small systems - 200 to 400 tons per day - is promising. Three commercial systems are under construction and firm will enter into typical industrial contracts.

Monsanto Enviro-Chem. Best application is for large systems - 1000 plus tons per day - with close coupled steam generation. Until operating problems of

Baltimore demonstration plant are resolved, late 1976 at the earliest, Monsanto will not sell system on commercial basis.

Moore Powergas. Produces cool low-BTU gas suitable for combustion with conventional burners. Providing only limited conditioning of solid waste is required prior to charging to the reactor, relatively small scale plants should be feasible. A demonstration plant, operating on wood waste, started-up in April 1976 and operating experience is very limited. Satisfactory operation of a demonstration plant, charged with MSW, is a requisite before the system can be considered for general commercial application. A schedule for construction of such a plant has not yet been established.

Occidental Research. Complex front end and pyrolysis process make this system suitable only for large regional installations. In any case, since product is a synthetic oil which can be stored and transported, there is limited advantage for integration with industrial plants. System will not be available for commercial application before mid-1977.

Union Carbide. System is quite well proven at South Charleston demonstration plant and is now being offered by Union Carbide under commercial contractual terms. Technology is most appropriate of any of the systems developed to date for production of medium-BTU gas for direct firing or chemical feedstock. Economies of scale associated with integrated oxygen plant will tend to make system suitable only for relatively large scale operations - 700 plus tons per day.

4.0 INCINERATION WITH HEAT RECOVERY

Conventional tumbling grate or semi-suspension solid waste incinerators can be used to recover energy from solid waste in the form of steam. Several incinerators with heat recovery have been constructed in Canada during the last five years. Features of these installations are compared below.

Location	Year in Service	Type of Firing	Units/Unit Capacity (tons/day)	Steam Generation Capacity (1000 lb/hr)
Montreal	1971	Tumbling Grate	4 at 300	400
Hamilton	1972	Semi-Suspension	2 at 300	210
Quebec City	1974	Tumbling Grate	4 at 250	325

The Montreal and Quebec City plants employ tumbling grates of European design (Von Roll). Raw solid waste is charged directly to the furnace by means of clam-shell cranes. A conventional water wall boiler configuration is used to generate steam. In the case of the Montreal plant only limited use is made of the steam for plant auxiliaries and district heating. The Quebec City plant produces steam for a nearby pulp and paper mill owned by Reed Paper.

At the Hamilton plant, raw refuse is shredded to minus 4 inch material, ferrous metal is magnetically removed and the solid waste is combusted in semi-suspension spreader stoker boilers, similar in design to modern hog fuel units. Steam utilization is limited to plant auxiliaries.

Over 40 large tumbling grate incinerator/boilers have been constructed in Europe during the last 10 years. Steam is extensively used for district heating and in many cases for power generation. Greater concentration of population and higher fuel and power costs contribute to more favourable conditions for such plants in Europe than in Canada and the United States. While several plants have been constructed in the U.S. during recent years, only three effectively recover energy - Braintree and Saugus in Massachusetts and Nashville, Tennessee.

It is possible to integrate large scale incinerators with industrial plants. The installation at Quebec City is a good example. Principal technical requirements are a steam load of sufficient size with limited seasonal fluctuation and sufficient operating flexibility to accommodate fluctuating steam supply. Large pulp and paper operations meet these criteria. Unfortunately, it is not common for such plants to be located in urban areas where adequate supplies of solid waste are available. For example, a preliminary review indicates that none of the pulp and paper facilities located in metropolitan Toronto would be appropriate for integration with a relatively large central incinerator.

Oil refineries are typically able to utilize waste gases to generate a major portion of process steam requirements. Integration of a large scale incinerator with a refinery is a possibility. Other potential steam users of this class include petrochemical, fertilizer and rubber plants.

The conventional incinerator approach has promise for certain industrial applications. In addition, there may be opportunities to employ this technology for district heating and cooling in central business districts or for power generation. In the latter case, a limit on maximum steam temperature to avoid boiler corrosion results in relatively poor thermal efficiency and increases capital costs.

In summary, conventional incineration with heat recovery has limited potential for general application for industrial plants but could be attractive for specific situations. The installation at Quebec City is a good example of a situation where this approach fits well.

5.0 REFUSE DERIVED FUEL

Several systems have been developed to produce refuse derived fuel (RDF) from solid waste. These systems employ shredding followed by removal of ferrous and non-ferrous metals and other inerts, such as glass and stone. Additional processing may include drying and briquetting.

Solid waste beneficiation, production of RDF, provides a fuel which has substantially improved qualities over raw solid waste. Nevertheless, ash content is relatively high and application must still be limited to firing boilers or other systems which are provided with efficient grate ash and fly ash handling systems. Two general approaches for utilization of RDF for steam production can be considered.

RDF can be used as a supplementary fuel in large utility boilers. The Watts from Waste project which will provide for firing of some 1000 tons per day of RDF at Ontario Hydro's Lakeview Generating Station is an example of this approach. By limiting RDF to about 15 percent of total fuel input, potential problem areas such as stack gas treatment, grate ash removal and boiler corrosion are mitigated.

Alternatively, it is possible to utilize RDF, in either fibre or briquette form, as a prime fuel in industrial scale boilers. The criteria for this approach are, however, fairly limiting. Key boiler requirements include:

- Spreader-stoker fuel feed, semi-suspension or grate burning.

- Efficient grate ash removal. A travelling grate is desirable but a fixed grate can be used if solid waste feed can be interrupted during grate cleaning. This requires that oil or gas be used while grate cleaning is underway or that steam generation can be interrupted.

- Effective particulate removal from stack gases; high efficiency electrostatic precipitators, high energy scrubbers or fabric filters.

- Moderate steam conditions. Unless PVC plastic is removed from RDF, boiler corrosion is indicated to be a significant problem at steam temperatures exceeding about 425^{o} C (800^{0} F).

A typical coal-fired spreader stoker industrial boiler would generally conform with the above criteria. It is believed, however, that there are a limited number of such units operating in Ontario. Furthermore, many of the existing coal-fired boilers are located at pulp and paper mills, remote from major solid waste sources. Of some 1.2 million tons of coal used by manufacturing industries in 1972, smelting and refining and pulp and paper mills accounted for almost 70 percent or 545,000 and 295,000 tons respectively. Nevertheless, there are several promising industrial situations where RDF could provide a significant substitute for coal.

Technical limitations of RDF also impair the potential for using solid waste for direct firing applications such as cement and lime kilns. While considerable research on this approach has been completed by others and direct firing of RDF may be technically feasible, an adequate demonstration run is required to properly assess impact on production capacity and product quality.

The characteristics of RDF produced by several selected systems along with characteristics of industrial coal and hog fuel are compared in Appendix 5.

6.0 GENERAL FEASIBILITY FOR INDUSTRIAL APPLICATION

6.1 Technical Feasibility

All of the alternatives considered are suitable for production of steam. There are, however, differences in the suitability of the systems to generate steam at temperatures above 425° C (800° F), to control heat release and meet load fluctuations, and for application over a range of capacity.

For direct firing applications, system technical feasibility is more difficult to assess. For some potential applications, such as firing of cement kilns with RDF, carefully monitored demonstration programs are required before the impact on product quality and production rate can be evaluated with sufficient reliability for commercial application.

Technical feasibility of selected systems for likely applications is illustrated by Figure 1. These ratings are essentially qualitative and technical feasibility is considered to include obvious unsuitability for small scale facilities.

FIGURE 1

TECHNICAL FEASIBILITY FOR SELECTED APPLICATIONS

	Andco-Torrax	Monsanto Enviro-Chem	Moore Powergas	Occidental Research *	Union Carbide	Conventional Incineration	RDF *
<u>Steam Generation</u>							
100,000 lb/hr max., 800^{o}F max.	G	P	G	G	P	P	G
300,000 lb/hr plus, 800^{o}F max.	G	G	G	G	G	G	G
200,000 lb/hr plus, 850^{o}F plus	P	P	G	G	G	P	P
Close output control	U	P	G	G	G	P	M
<u>Direct Firing</u>							
Cement Kilns, 200 $\bar{M}$BTU/hr plus	P	P	G	G	G	P	U
Lime Kilns, 200 $\bar{M}$BTU/hr plus	P	P	G	G	G	P	P
Dryers, 100 $\bar{M}$BTU/hr max.	M	P	G	G	P	P	M

G - Good
P - Poor
U - Uncertain
M - Marginal

* - Application of fuel produced, assumes large central solid waste processing plant.

6.2 Economic Feasibility

Economic feasibility can only be rigorously assessed for a site specific case. Nevertheless, in order to appraise the potential for use of solid waste as industrial fuel, it is clearly necessary to examine economic parameters. A basic economic/financial analysis of two P/G systems follows in this section. Costs and benefits can be considered in the following categories:

Fixed Costs. Amortized cost of capital, property tax and insurance. Of these items, amortized cost of capital is clearly the most important. Capital costs of P/G systems or conventional incinerators lie in the range of $20,000 to $30,000 per daily ton of solid waste processing capacity. That is, a system of reasonable industrial size, say, 350 tons per day producing 100 $\overline{M}$BTU per hour, would cost $7 to $10 million.

The amortized cost of capital for a private firm is dependent upon a number of factors, including cost of debt and equity, ratio of debt to equity and corporate tax position. A typical amortized cost of capital, appropriate for investment in a solid waste energy recovery facility, would be 15 percent of the capital cost per annum. The assumptions underlying this value and the principal of its determination are detailed in Appendix 6.

Cost of property tax and insurance is estimated at a total of 1.5 percent of the capital cost per annum.

Variable Costs. Supervision and labour, maintenance materials and supplies, power and fuel. It is likely that significant savings in supervision and operating and maintenance labour costs could be achieved by integration of a solid waste processing plant with an industrial manufacturing facility. For developing technologies such as the P/G systems, accurate projection of maintenance costs is difficult until operating experience is available. An allowance of 5 percent of the capital cost per annum is a reasonable estimate for maintenance labour and materials.

Energy Value. The value of energy recovered from solid waste is the cost of alternative fuels. This was illustrated by Table 5 on page13. For the purpose of this analysis, energy values ranging from \$10 to \$25 per ton are appropriate.

Metals and Glass Recovery. Several of the processes examined include provision to recover glass and ferrous and nonferrous metals. Analysis of Ontario solid waste material, included in Reference 7, indicates that the value of such recovered materials could approach \$7 per ton of solid waste. For the P/G systems, considered most suitable for industrial applications, it is probable that only partial recovery of ferrous metals would be provided. For analysis, it is assumed that 100 lbs of ferrous metal with a value of \$20 per ton, equivalent to \$1.00 per ton of solid waste, would be recovered.

6.3 Economic Feasibility for Typical Cases

To demonstrate economic feasibility, two P/G plants have been selected for analysis, a 350 ton per day facility and a 700 ton per day facility. These alternatives have been selected to demonstrate economies of scale in a size range considered appropriate for industrial application. In general terms, it is considered that economic feasibility is not highly sensitive to steam generation vs fuel gas production and it is intended that the analysis, which follows, would be appropriate for either case. For a specific case, the flexibility to convert existing boilers, kilns or dryers to direct firing of fuel gas produced by P/G of solid waste could be of significant advantage.

Analysis is based on the following criteria.

TABLE 6
P/G SYSTEM OPERATING AND COST FACTORS

	Unit	Case A	Case B
MSW Processed	tons/day	350	700
MSW Processed	tons/annum	115,000	230,000
Capital Cost	$/daily ton	30,000	25,000
Total Capital Cost	$ Million	10	17.5
Operating Manpower		15	24
Avg. Cost per Man	$/annum	20,000	20,000
Power Consumption	KWH/ton	60	60
Power Consumption	MWH/annum	6,900	13,800
Power Cost	$/KWH	.015	.015
Mobile Loaders		1	2
Loader Operation	hrs/annum	2,000	4,000
Loader Operating Cost	$/hr	20	20

Estimated operating costs are summarized in Table 7.

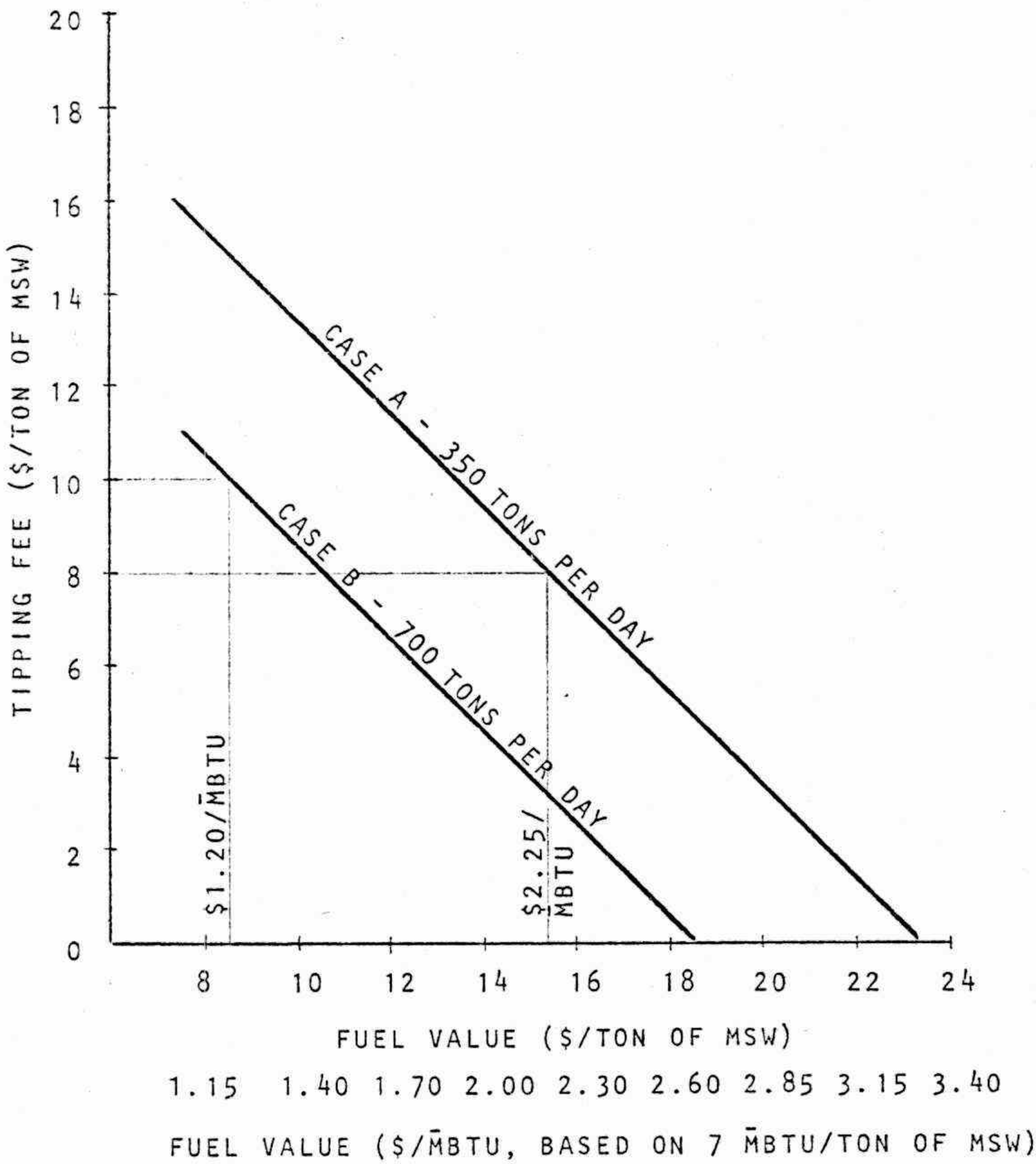
TABLE 7

P/G SYSTEM OPERATING COSTS

	Case A-350 TPD		Case B-700 TPD	
	$/Annum	$/Ton	$/Annum	$/Ton
Fixed Costs				
Amortized Cost of Capital (15%)	1,500,000		2,625,000	
Property Taxes and Insur. (1.5%)	150,000		263,000	
Total Fixed Cost	1,650,000	14.40	2,888,000	12.55
Variable Costs				
Labour	300,000		480,000	
Power	104,000		207,000	
Mobile Loaders	40,000		80,000	
Maintenance (5%)	500,000		875,000	
Total Variable Cost	944,000	8.20	1,642,000	7.15
Total Cost	2,594,000	22.60	4,530,000	19.70
Less Fe Recovery	115,000	1.00	230,000	1.00
Net Cost	2,709,000	23.60	4,300,000	18.70

The net cost must be met by the fuel value plus a disposal charge (tipping fee). The required tipping fee vs fuel value is shown graphically in Figure 2.

FIGURE 2
TIPPING FEE VS FUEL VALUE



In some cases, incineration is currently the best available option for disposal of MSW. In such instances a competitive tipping fee would be \$8 to \$10 per ton. In other areas, conveniently located land-fill sites which conform with environmental protection requirements are available and competitive tipping fees could be as low as \$4 to \$5 per ton.

For near term application it is considered that use of solid waste as industrial fuel will likely only be feasible in areas where high cost disposal options must be employed. Assuming \$8 to \$10 per ton is a competitive tipping fee, the corresponding fuel cost is \$1.20 to \$2.25 per $\bar{M}$BTU. These fuel costs are comparable to current natural gas and oil costs and thus it is evident that use of solid waste as fuel could be feasible in certain cases.

7.0 RECOMMENDATIONS

Analyses summarized in this report indicate that use of solid waste as fuel for certain industrial applications is technically and economically feasible. Furthermore, there are environmental and social advantages for this approach in comparison to alternatives such as incineration and sanitary land fill. Therefore, the following recommendations are proposed:

1. In selected regions, identify and characterize industrial plants which generally meet the criteria favouring use of solid waste as fuel (refer to page 6).

2. Select one or more promising situations for site-specific feasibility analysis. Analysis should cover incineration/steam generation as well as pyrolysis/gasification. Preferably, site-specific studies should be carried out jointly by the industrial firm and appropriate public agencies.

3. In selected regions, identify and characterize industrial boilers suitable for utilization of RDF (refer to page 33).

4. Examine the feasibility of production of RDF and transport to industrial plants.

APPENDIX 1

ABBREVIATIONS USED IN THIS REPORT

BTU	British Thermal Unit
I Gal	Imperial Gallon
KWH	Killowatt-Hours
$\bar{M}$BTU	Million British Thermal Units
MCF	Thousand Cubic Feet
MSW	Municipal Solid Waste
MWH	Megawatt-Hours
P/G	Pyrolysis/Gasification
RDF	Refuse Derived Fuel
TPD	Tons per Day

APPENDIX 2

LIST OF REFERENCES

1. Ontario Statistical Centre, Consumption of Fuel and Electricity by Ontario Manufacturing Industries 1972, May 1975.

2. Andco-Torrax Limited, General Information on the Andco-Torrax Process for Slagging Pyrolysis of Solid Refuse, undated.

3. D.B. Sussman, Baltimore Demonstrates Gas Pyrolysis - Resource Recovery from Solid Waste, EPA Interim Report SW-75d.i, 1975.

4. V.L. Hammond et al, Pyrolysis-Incineration Process for Solid Waste Disposal, Battelle Pacific Northwest Laboratories, Dec. 1972.

5. S.J. Levy, San Diego County Demonstrates Pyrolysis of Solid Wastes, EPA Report SW-80d.2, 1975.

6. Union Carbide, A Synopsis of the Operation of the Purox System Demonstration Plant at South Charleston, West Virginia, Undated.

7. Kilborn Engineering Limited, Resource Recovery Center (a report completed for the Ontario Ministry of the Environment), April 1974.

APPENDIX 3

COMPARISON OF PYROLYSIS/GASIFICATION SYSTEMS

Item	Unit	Andco-Torrax	Monsanto Enviro-Chem	Moore Powergas	Occidental Research	Union Carbide
Energy Product		Steam	Steam	Fuel gas	Syn oil	Fuel gas
Waste Preparation		None	minus 4"	minus 4"	minus 1/16"	minus 4"
Residue		Inert frit	Char/ash	Ash	Char/ash	Inert frit
Char Produced *	%	-	8	-	5	-
Mode of Operation		Slagging	Partial slagging	Dry ash	Dry ash	Slagging
Operating Inputs						
-Aux. Fuel	US Gal/ton	-	7.1	-	.7	-
-Power	KWH/ton	50	67	60	135	120
Output (based on 9.2 $\bar{M}$BTU/ton MSW)	$\bar{M}$BTU	6.6 as steam	5.5 as steam	6 to 7 as gas	4.1 as oil	6.9 as gas
Energy Efficiency	%	68 as steam (Andco)	51 as steam (Ref. 3)	approx. 70 as gas (Est.)	39 as oil (Ref. 5)	66 as gas (Ref. 6)
Operating Installations		Orchard Park**	Baltimore	Clinton ***	San Diego ****	South Charleston

* Percent of input weight (carbon)
** Other units under construction at Luxembourg, Grasse and Frankfurt
*** Started up in April 1976
**** Under construction

APPENDIX 4

COMBUSTION CHARACTERISTICS OF P/G SYSTEMS

	Unit	Andco-Torrax (1)	Union Carbide (2)	Moore Powergas (3)	Natural Gas
Gas Temperature	°F	800	120	120	70
Volume Composition (% by volume)					
Hydrogen		12.7	29.2	15.7	
Carbon Monoxide		13.1	41.6	13.8	
Carbon Dioxide		10.1	12.4	12.2	
Methane		1.9	3.5	1.2	90
Ethane Plus		0.3	0.9	0.4	10
Nitrogen		43.2	0.9	45.2	
Oxygen		1.5	0	0	
Water		17.2	11.5	11.5	
		100.0	100.0	100.0	100
Calculated (0% excess air)					
Heat Value (4)	BTU/cu.ft.	110	252	102	946
Combustion Air	ACF/$\bar{M}$BTU	7,000	8,600	8,700	10,800
Flue Gas (5)	ACF/$\bar{M}$BTU	98,000	90,000	103,000	97,000
Flue Gas Temperature (5)	°F	3,100	3,900	2,800	4,000
Products of Combustion (0% excess air) (% by volume)					
Water		21.0	17.9	17.7	18.8
Carbon Dioxide		15.6	21.0	16.1	9.8
Nitrogen		63.4	61.1	66.2	71.4
Oxygen		0	0	0	0
		100.0	100.0	100.0	100.0

APPENDIX 4

COMBUSTION CHARACTERISTICS OF P/G SYSTEMS

	Unit	Andco-Torrax (1)	Union Carbide (2)	Moore Powergas (3)	Natural Gas
Gas Temperature	^{o}F	800	120	120	70
Volume Composition (% by volume)					
Hydrogen		12.7	29.2	15.7	
Carbon Monoxide		13.1	41.6	13.8	
Carbon Dioxide		10.1	12.4	12.2	
Methane		1.9	3.5	1.2	90
Ethane Plus		0.3	0.9	0.4	10
Nitrogen		43.2	0.9	45.2	
Oxygen		1.5	0	0	
Water		17.2	11.5	11.5	
		100.0	100.0	100.0	100
Calculated (0% excess air)					
Heat Value (4)	BTU/cu.ft.	110	252	102	946
Combustion Air	ACF/$\bar{M}$BTU	7,000	8,600	8,700	10,800
Flue Gas (5)	ACF/$\bar{M}$BTU	98,000	90,000	103,000	97,000
Flue Gas Temperature (5)	^{o}F	3,100	3,900	2,800	4,000
Products of Combustion (0% excess air) (% by volume)					
Water		21.0	17.9	17.7	18.8
Carbon Dioxide		15.6	21.0	16.1	9.8
Nitrogen		63.4	61.1	66.2	71.4
Oxygen		0	0	0	0
		100.0	100.0	100.0	100.0

4. Heat value includes sensible heat of gas, at gas temperature specified, plus lower heating value of combustibles. Gas volume is at standard conditions - 25°C (77°F) and 1 atmosphere.

5. It is assumed that combustion air would be pre-heated to 175°C (350°F). Adiabatic combustion is assumed (no allowance taken for combustion unit heat losses).

6. Higher heating value (HHV) at the reference state of 25°C (77°F) on a wet gas basis. Includes latent heat of condensation. Gas volume is at standard conditions - 25°C (77°F) and 1 atmosphere.

APPENDIX 5

COMPARISON OF SELECTED RDF, COAL AND HOG FUEL CHARACTERISTICS

	Unit	CEA Eco Fuel	OXY (Garret)	Union Electric	Black Clawson		Raw MSW	Hog Fuel	Coal*
Processing Operation		Dry	Dry/Wet	Dry	Wet		-	Dry	Dry/Wet
Max. Particle Size	in.	1/4	1/2	1	1		as received	2	1
Ash	%	5 to 9	8 to 14	7 to 54 (18 avg.)	10 to 12		15 to 40 (18 typ.)	1 to 5	3 to 15
					Fibre	Pellets			
Moisture	%	2	10	3 to 63 (27 avg.)	50	20	20 to 40	45 to 65	2 to 20
Density	lb/cu.ft.	30		37 to 68	29	30	25 to 35	15 to 25	40 to 55
Higher Heating Value	BTU/lb	7500 to 8000	6300	2300 to 7600 (5000 avg)	4200	6700	3500 to 5500	4000 to 5500	11,000 to 15,000
Recovery: Fe		Yes	Yes	Yes	Yes		-	-	-
Al Cu, etc.		Yes	Yes	Partial	Yes		-	-	-
Glass		Yes	Yes	Partial	Yes		-	-	-
Paper fibre		No	No	No	Yes		-	-	-

* Characteristics vary widely by rank.

APPENDIX 6

AMORTIZED COST OF CAPITAL

The amortized cost of capital for any specific installation is dependent on a number of parameters. For analysis the following factors are assumed:

1. \$10 million capital financed by 60 percent debt and 40 percent equity.

2. Debt interest at 11.5 percent with principal due in three equal installments at 5, 10 and 15 years.

3. Capital cost allowance 20 percent. It is assumed that almost the total investment would fall in Class 8.

4. Corporate tax rate 50 percent.

5. The firm has other profitable operations so that full allowable capital cost allowance can be taken during initial years of operation to produce a corporate tax credit.

6. Project life 15 years.

7. Return on investment is calculated on a discounted cash flow basis (DCF).

In Table A6-1, it is assumed that the amortized cost of capital is 15 percent of the capital investment. That is, a competitive transfer price for fuel produced by the

facility must provide for an annual contribution to capital (debt servicing and return on equity investment) of 15 percent of the capital cost.

Using these assumptions, the DCF return on equity investment is estimated at 13.5 percent. This is likely not an acceptable level for most firms, however, the analysis does not provide for fuel costs increasing on real terms relative to other costs.

For preliminary analysis, an amortized cost of capital of 15 percent is considered reasonable.

TABLE A6-1

CASH FLOW ANALYSIS ($ MILLIONS)

Year	Amortized Cost of Capital	Debt Interest (11.5%)	Debt Principal Retirement	CCA (20%)	Taxable Income	Corp. Tax	Cash Flow	Cum. Cash Flow	Present Value (15%)	Present Value (12%)
1	1.50	.69		2.00	(1.19)	(.60)	1.41	1.41	1.23	1.26
2	1.50	.69		1.60	(.79)	(.40)	1.21	2.62	.91	.96
3	1.50	.69		1.28	(.47)	(.24)	1.05	3.67	.69	.75
4	1.50	.69		1.02	(.21)	(.10)	.91	4.58	.52	.57
5	1.50	.69	2.00	.82	--	--	(1.19)	3.39	(.59)	(.67)
6	1.50	.46		.65	.39	.20	.84	4.23	.36	.43
7	1.50	.46		.52	.52	.26	.78	5.01	.29	.35
8	1.50	.46		.42	.62	.31	.73	5.74	.24	.29
9	1.50	.46		.34	.70	.35	.69	6.43	.20	.25
10	1.50	.46	2.00	.27	.77	.39	(1.35)	5.08	(.33)	(.43)
11	1.50	.23		.21	1.06	.53	.74	5.82	.16	.21
12	1.50	.23		.17	1.10	.55	.72	6.54	.13	.19
13	1.50	.23		.14	1.13	.57	.70	7.24	.11	.16
14	1.50	.23		.11	1.16	.58	.69	7.93	.10	.14
15	1.50	.23	2.00	.09	1.18	.59	(1.32)	6.61	(.16)	(.24)
Totals	22.50	6.90	6.00	9.64	5.97	2.99	6.61		3.86	4.22